Becoming a good forces teacher

Bob Kibble

Successful teaching of an important physics topic requires comfortable subject knowledge and an understanding of a pedagogy to promote learning

There is no shortage of material expressing concerns and offering strategies for teaching about forces. When I was a young teacher the issues were explored for me through the writing of, amongst others, John Warren (1979) and the authors of the Nuffield O-level physics teachers' guides. The Force Concept Inventory (Hestenes, Wells and Swackhamer, 1992) offers a host of problems for group discussion, as does the more recent work of the Evidence-based Practice in Science Education (EPSE) project managed by the University of York. Both resources offer teachers diagnostic questions to promote discussion and explore conceptions. The *Supporting Physics Teaching (SPT) 11–14* materials available through the Institute of Physics (2006) include a CD-ROM devoted to issues relating to the learning and teaching of forces. I was fortunate to contribute to the latter development and found myself thinking hard about what I had learned as a teacher and teacher-educator and also what I still needed to learn about this topic. In this article I explore the main areas of concern and offer some pointers to support both teachers and learners.

The educational challenge is multidimensional. It involves the use of language and the meaning of words, the attraction of intuitive but erroneous ideas, and the reformulation of the real world through abstraction and modelling, and it faces the problems of practical experiments in a world where friction cannot be eliminated. The solutions are equally complex and need to address all the above. Being a good 'forces' teacher is not an easy option but a professional aspiration for us all. We all need to be learners and we all need to constantly revisit and reflect on our classroom strategies. The journey is as much a challenge for teachers as it is for learners.

ABSTRACT
Learning how best to teach the difficult ideas relating to forces is itself a journey for the teacher. Practical work alone is unlikely to secure the desired concept formations. This article suggests a number of strategies which might be explored with secondary-age pupils.

Language and the meaning of words

Perhaps the single most powerful tool to support learning is the voice of the learner. Speaking, thinking about speaking, listening and responding to others who share their thoughts have to find a central place in teaching strategies. Such activities should take precedence over copying notes and diagrams, over doing practicals and revising for exams. I am not saying that activities such as practicals are without value, but to engage in a routine practical activity without talking about it, what it means, what you think about it and what you have learnt is simply to go through the motions. Good teaching will allow space and time for dialogue, will give learners confidence to talk and listen and a message that '*it is OK to chat about what we are doing and why*'. Many of the strategies promoted through the formative assessment movement, such as open questions, concept cartoons (Keogh and Naylor, 2000) and group challenges, are about teaching through listening to learners and encouraging their voices.

Having the confidence to talk about what one is doing should be part of early learning experiences. In primary classrooms children will be encouraged to describe how it feels to stretch elastic bands, to push toy trolleys, to play tug-o-war, to lift up bags of shopping and to test the strength of plastic bags, and so on. Such activities will no doubt result in a language of push, pull, twist and stretch. Teachers have the job of showing that such actions can be described using a vocabulary of 'force' and

'balance'. Such early learning will be characterised by egocentric, real-world experiences where children talk about their own aching arms when they lift a shopping bag or the way they slide over a slippery floor. In secondary education the journey forward will lead these learners towards reformulating such experiences using modelling strategies, such as drawing diagrams and using arrows to describe where forces are acting.

First experiences with forces will no doubt relate to actions: '*I am pushing the trolley with a force*' or '*we can change the shape of a cushion by using a force*'. Such activities are likely to indicate that forces are associated with motion. The fact that in many cases there will be a number of forces acting on any object is unlikely to be appreciated. The force felt by the learner, their pull on the trolley, is likely to be the only obvious force making an appearance in the learning process. The appreciation that other forces are acting (gravitational, frictional) is not an issue for early learning but will be part of the forces journey in secondary classrooms.

In writing materials for the SPT project, I chose to consider forces in equilibrium as a starting point, recognising that most real-world force situations are those of balanced forces. I considered that teaching about single forces acting on an object, resulting in an appropriate acceleration, might appear simpler but in reality was a special case and one which, even with air tracks, was unlikely to be in evidence for learners age 11–14. You will have to decide when to teach about balanced forces and unbalanced forces. In a world where all things are acted upon by at least one force, the force of gravity, to notice that most objects are not accelerating (just look around the room) is to appreciate that our lives are dominated by equilibrium and balanced forces. That was my starting point.

Returning to language, how might balanced forces be described? A simple rule is to identify the cause of the force and the object on which the force is acting and to separate these two. Hence '*I am applying a force ... the force is pushing the trolley*' or '*the Earth's gravity applies a force which acts on the apple ... the force acting on the apple pulls it downwards*'. Such formulations are not easy for learners if language is not their forte. The grunts and moans characterising the restricted codes which often transfer from playground to classroom need to be transformed into confident, articulated sentences and, not only that, the sentences must use a vocabulary (force, apply, balance, etc.) that many learners might not use frequently. So let's suppose you have created an '*it's good to talk physics*' atmosphere in your classroom. Which key ideas might you focus conversation upon?

Intuition and 'hot-spot' ideas

Research into children's understanding has identified those key areas where misconceptions are likely and also what these misconceptions might be. Studies such as the Science Processes and Concept Exploration (SPACE) project, carried out from 1990 to 1998, and the work of Ros Driver's team in the Children's Learning in Science Project at the University of Leeds (Driver *et al*., 1994) indicate a range of areas where children bring alternative or naive explanations into the classroom. Teachers would do well to become familiar with the messages from such research for several reasons. The first is that they might find themselves reflected in the mirror of the research findings. Misconceptions are not limited to children. Many adults, and some teachers – no, that's all teachers – will find that they carry particular misconceptions in their own understanding. As embarrassing as this voyage of self-discovery might be, we do owe it to learners to at least get the ideas right in our own minds.

Once we are aware of the most likely areas of misunderstanding we can look out for evidence from learners, most often through listening to classroom dialogue, of their thinking on these key ideas. More importantly, we can engineer our teaching to deliberately expose learners to challenging situations where such misconceptions will arise. A well-chosen concept cartoon or a question from the EPSE research will provide an excellent diagnostic challenge to target a forces 'hot-spot' and deliberately promote learner talk. Figure 1 gives such an example taken from the EPSE research.

So a message here is that good forces teachers will be aware of likely misconceptions but they won't just wait for misconceptions to arise. They will engineer their teaching to deliberately expose learners to such challenging ideas.

So what are the hot-spot conceptual areas to be aware of when teaching forces? A selection is included in Table 1.

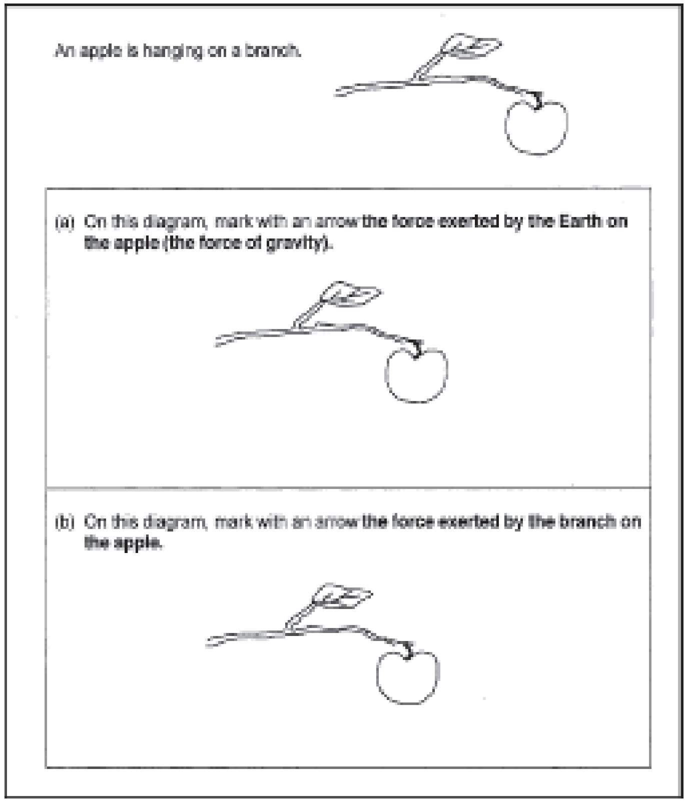


Figure 1 A diagnostic question to explore ideas about forces.

Table 1 Some 'hot-spot' conceptual ideas

Hot-spot idea	*Notes for teachers*
Heavier objects fall faster than lighter objects	The force due to gravity acting on an object can be experienced by carrying that object. A weighing machine will allow you to measure and record this force. The bigger the force acting on an object the faster it will accelerate. So why doesn't a heavier object fall faster? The solution to this conundrum lies in appreciating that the more massive an object, the harder it is to speed it up. This property is known as the inertia of the object. So heavier objects on the one hand are acted upon by a greater gravitational pull but also require a greater force to accelerate their greater mass. A 2 kg mass will weigh more than a 1 kg mass, but will require twice the force to accelerate it at a particular rate. The effect is that all masses accelerate under gravity at the same rate, about 10 m s^{-2}.
Moving objects carry a force with them and lose this force when they stop	This intuitive idea has much merit. We do sense a quantity stored in a moving object. We give it the term 'kinetic energy'. Moving objects also carry a 'momentum'. When an object stops moving it will have lost its momentum and transferred its energy to a different energy store. Here is a case for establishing the precision with which we ascribe meaning to words in physics. If the word 'force' has a part to play in this story, it is as the action which started the object moving in the first place and the action which slows the object. The force is the mechanism by which energy is transferred to or from the object. Once moving, the initial forcing action becomes history.

(continued)

Table 1 (*continued*) Some 'hot-spot' conceptual ideas

Hot-spot idea	*Notes for teachers*
A surface, such as a table top, can't exert a force upwards	The origin of support forces, i.e. those that stop objects falling through the floor, requires explanations which draw on microscopic stories of the forces between particles. Some macroscopic support systems, a mattress or cushion for example, clearly show the effect of internal forces, the deformation of springs or foam, which provide an upwards action on an object. The surface of a table could be imagined to be like the springs in a mattress, deformed by a microscopic amount.
The Earth's gravity reaches up only as far as the atmosphere	The intimate link between gravity and atmosphere is a common misunderstanding. It is the root of the misconception about orbiting astronauts being 'beyond the pull of gravity because they are above the atmosphere'. The Earth's gravitational field reaches out to infinity. It becomes weaker with increasing distance from the Earth. An orbiting satellite moves in a circle precisely because it is acted upon by a gravitational force. Without such a force the satellite would move in a straight line and continue into deep space.

Forces spectacles: reformulating and modelling the real world

A defining feature of science, and physics in particular, is the way in which complex real-world scenarios are reduced and simplified by extracting key elements and focusing on these. Being able to sketch a diagram of a practical situation and draw only the salient components is a refined skill and ought to be a target for teaching. We need to share this skill with learners and teach them how to appreciate models and why such models are of value. Of course we also need to explain the limitations of our models. This is true of all areas of physics and is, as said before, a defining feature of an education in physics. In teaching about how physicists approach forces through modelling you will need to include the introduction of symbols to represent the direction and action of forces. We show forces as arrows. The ability to take a real-world situation, where there are no obvious arrows labelled 'force', and create a sketch of salient objects and force arrows is a refined skill and as important as the ability to plot a graph or perform a calculation. I call this skill the ability to look at the world through 'forces spectacles'. An example of how a real-world situation might be reduced and simplified using 'forces spectacles' is shown in Figure 2.

The simplification offered by the modelling process allows us to focus our language on those parts of the situation that are important. In this example the diagram offers a smoother path towards statements such as '*the forces acting on the mass are* ...'. The first diagram excludes the extraneous objects such as table, walls, person, which appear in the real world of the photograph. The second diagram offers a further reduction and shows two forces acting on the single mass. (Of course the support system, including the table and retort stand, can be considered as part of the forces picture as indeed might the Earth, but in so doing we run the risk of drifting towards greater complexity. For beginners, let's take one object at a time.) There are conventions that we use in this modelling process: how and where to draw the arrows, how far to reduce the target object – do we go as far as a point mass for example? These conventions ought to be part of the modelling learning journey.

So the message for good forces teachers is to be transparent about this modelling process. Learners will need chances to engage in their own simplifications, not just copy ours, and of course we want them to talk about the process as it happens. If the modelling process is presented as a defining feature of learning physics then it will appear in other lessons (electric circuit diagrams, magnetic field lines, electrons and atoms, etc.) and will become a far more natural part of the learning experience.

Your learners as a team of researchers

A powerful strategy to encourage learning is to involve learners in a process of thinking about their own learning. Seeing oneself as a learner, often called metacognition, is to recognise one's role in the

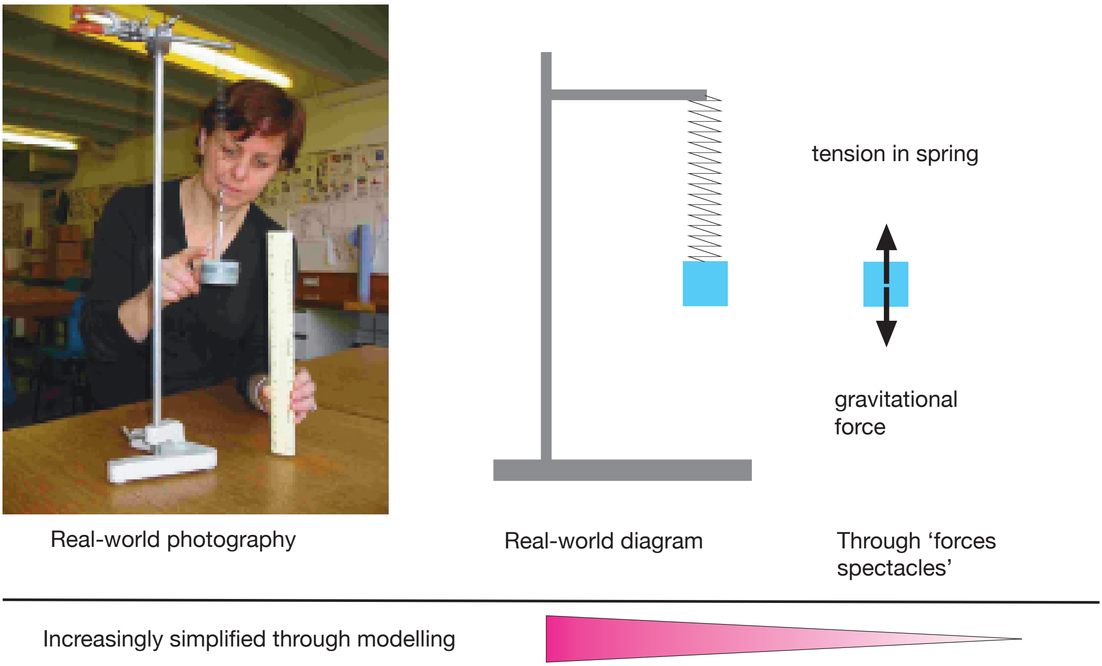


Figure 2 The real world of stretching springs (photo) can, when seen through forces spectacles, be reduced to a simple model sketch.

lesson and to appreciate that this whole enterprise is not about the teacher or the subject but about you and, more importantly, how you think. Sophisticated metacognition will allow learners to describe their preferred learning styles, know what they need to help them understand, and recognise when ideas start to make sense. Teachers can encourage such self-awareness by engaging learners in activities that recognise the variety of ideas within a classroom. The diagnostic questions mentioned earlier provide a platform for small discussions that bring to the fore those preconceptions which reside within a group of learners. The process of listening to peers articulating their ideas, recognising the variety of ideas within the group and evaluating one's own ideas against this backdrop is a form of social construction, or reconstruction, of knowledge. Handled well such dialogue might lead to '*I used to think this but now I have changed my mind*' or better still '*It's cool to change your mind*'. Such phrases are the holy grail of metacognition.

Once learners start to appreciate that 'forces' is a topic where a number of intuitive ideas abound and that learning involves taking an interest in such ideas, it is quite possible, indeed not only possible but valuable, to involve a class in a small research project. The Force Concept Inventory and the EPSE research project offer some excellent problems which can be shaped into a 'Let's find out what family and friends think' homework exercise. You might for example select some 'hot-spot' problems and engage learners in the planning of their own research project based on these questions.

A class of 20 learners, each asking ten people about forces ideas, will yield enough data to build a lesson that not only focuses on these hot-spot ideas but exposes the problems of intuitive thinking and encourages an interest in metacognition. Figure 3 offers a suggestion for a pupil-research question sheet. Each pupil might take home a single question sheet and a dozen response slips. Once such a task has been undertaken and explored, there is no reason why you cannot use a similar pupil-researcher task to explore concepts in other areas of science.

In summary, the good forces teacher is likely not only to have good general teaching skills but to be someone who takes an interest in research and discussion about the way learners develop ideas and the precise hurdles which research suggests that learners face when learning about forces. They will be aware of their own personal journey towards a satisfying understanding of forces. They

What do you think about forces?

We are carrying out some research about the ideas people have about forces. We hope you can help out. This is not a test. You don't need to write your name.

Please consider these situations and put your answers on the answer slip.

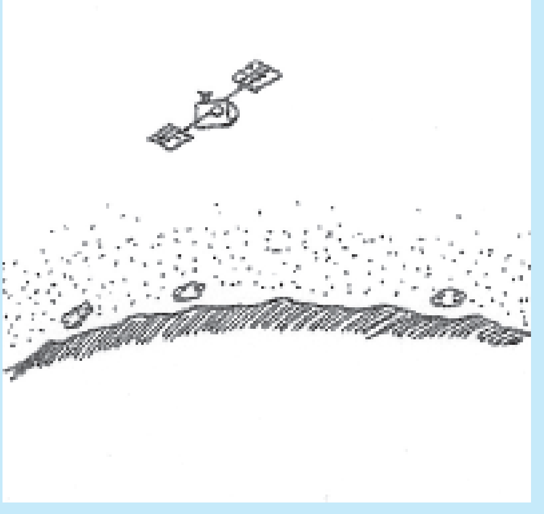
1. The diagram shows a tennis ball and a cricket ball released together.

Question:

Which ball will reach the ground first?

Why?

(Use the answer slip for your answer.)



2. Orbiting spacecraft are above the Earth's atmosphere and so are beyond the pull of gravity.

Question:

Is this true or false?

(Use the answer slip for your answer.)

Forces questions answer slip

1. Falling balls: What will happen is ...

This happens because ...

2. Orbiting spacecraft:

true [ ]

or false [ ]

Figure 3 Example of a worksheet to 'test' understanding of forces.

will be aware of the power of modelling as a tool for understanding complex ideas and the role of language and learners' voices in supporting a shared understanding.

It is clear to me that a good forces teacher requires skills and understanding over and above those included in a simple audit of physics subject knowledge. Such pedagogical knowledge will no doubt be a feature of initial teacher education courses and, one expects, will be developed through the process of teaching. I hope that sufficient time is allocated in ITE and CPD courses to establishing this critical pedagogical knowledge and to sharing approaches such as the ones I have outlined.

It is interesting to reflect on what this article might have offered if written in 1975 when I started out as a teacher. Perhaps then a good forces teacher might have been encouraged to secure funds for a class set of ticker timers, or, in modern parlance, motion dataloggers, and store them appropriately. I might have urged you to always engage pupils in practical work of their own to discover or uncover relationships between force and acceleration for example. Today my message is quite different. Of course practical activities have a place but they will not in themselves move learners forward to face the challenge of concept formation and reformation. Using selected hot-spot scenarios set against group discussion, noisy banter, listening and sharing ideas and appreciating how thinking works and how ideas are shaped are my messages for today's teachers.

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What did *you* think?

Hints to promote discussion if you are struggling with the questions on page 39.

1 Think how to alter the centre of gravity of the can, so that it is in a state of unstable equilibrium.

2 Consider the effect of sunlight on melanocyte cells.
Consider the function of melanin.

3 Consider:
- the direction and change in size of the induced emf as the magnet enters the coil;
- the direction and change in size of the induced emf as the magnet moves through the coil;
- the direction and change in size of the induced emf as the magnet leaves the coil;
- the size of the induced emf when the magnet is distant from the coil;
- the effect, if any, of Lenz's Law on the acceleration of the magnet;
- whether the weight of the magnet or length of the coil will have a significant effect.

4 Consider whether the inverse square law applies to this light source.
Consider what happens to the observer's eye when viewing the streetlights.

5 Consider what wavelengths are reflected by the white paper, the red R and the blue R.
Consider the effect of the filter on reflected wavelengths.